IV. *A Contrivance to avoid the Irregularities in a Clock's Motion, occaſion'd by the Action of Heat and Cold upon the Rod of the* Pendulum. *By Mr.* George Graham, *Watch-Maker, F. R. S.*

WHereas ſeveral, who have been curious in meaſuring of Time, have taken Notice, that the Vibrations of a Pendulum are ſlower in Summer than in Winter; and have very juſtly ſuppoſed this Alteration has proceeded from a Change of Length in the Pendulum itſelf, by the Influences of Heat and Cold upon it, in the different Seaſons of the Year; with a View therefore of correcting, in ſome degree, this Defect of the Pendulum, I made ſeveral Trials, about the Year 1715. to diſcover whether there was any conſiderable Difference of Expanſion between Braſs, Steel, Iron, Copper, Silver, *&c.* when expoſed to the ſame Degrees of Heat, as nearly as I could determine; conceiving it would not be very difficult, by making uſe of two Sorts of Metals, differing conſiderably in their Degrees of Expanſion and Contraction, to remedy, in great meaſure, the Irregularities to which common Pendulums are ſubject. But altho' it is eaſily diſcoverable, that all theſe Metals ſuffer a ſenſible Alteration of their Dimenſions by Heat and Cold; yet I found their Differences, in Quantity from one another, were ſo ſmall, as gave me no Hopes of ſucceeding this Way, and made me leave off proſecuting this Affair any farther at that Time. In the Beginning of *December*, 1721. having Occaſion for an exact Level, beſides other Materials I made Trial of, Quickſilver was one; which, although I found it was by no Means proper for a Level, yet the extraordinary De-

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gree of Expanſion, that I obſerved in it, when placed near the Fire, beyond what I had conceived to be in ſo denſe a Fluid, immediately ſuggeſted to me the Uſe that might be made of it, by applying it to a Pendulum. In a few Days after, I made the Experiment, but with much too long a Column of Quickſilver the Clock going ſlower with an increaſe of Cold, contrary to the common Pendulum; however, it was a greater Confirmation of the Advantage to be expected from it, ſince it was eaſy to ſhorten the Column in any Degree required. The only Doubt I entertained, was, leſt there ſhould not be a proportional Expanſion and Contraction between the Quickſilver, and the Rod of the Pendulum, through the various Degrees of Heat and Cold, from the one Extreme to the other. To make this Experiment the more convincing, I placed the Clock in a Part of the Houſe, the moſt expoſed of any to the Changes of Heat and Cold, the Room having no Fire in it in the Winter, and expoſed to a South Sun, with Leads above it, which, in the Summer, made it extremely hot. I hung a Thermometer by it, and had likewiſe another Clock at no greater Diſtance from it, than was neceſſary to keep the Caſes from touching one another. This Clock had been made ſome Years before, with extraordinary Care, having a Pendulum about 60 Pounds in Weight, and not vibrating above one Degree and half from the Perpendicular; and which, in a more temperate Situation, had not alter'd above 12 or 14″ in 24 Hours, between Winter and Summer; but in this Place it altered 30″ a Day, between the hotteſt and coldeſt Weather, in the Year 1722, a Year no way remarkable for either Extremes. But this great Alteration was owing to the Situation I mentioned above, and which I made Choice of for the ſake of making the Experiment the more ſenſible.

The two Clocks being firmly skrewed to a Party-Wall, I began to make the firſt Trial of this Kind of Pendulum, *December* 18. 1721. and by *January* the third, perceiving the Pillar of Quickſilver conſiderably too long, I procured a ſhorter Glaſs, which I got ready by the eighth, and made uſe of, until the Beginning of *June* following: By which Time I was well ſatisfied of the Advantage of the Contrivance, notwithſtanding both theſe Pendulums were but rudely executed, and this laſt had the Pillar of Quickſilver too ſhort, but much nearer the true Length than the firſt. This encouraged me to provide another Glaſs, a little longer than the laſt, and to beſtow more Care upon all the Parts of the Pendulum that required Exactneſs. This being finiſhed, by the 9th of *June*, I began then to obſerve the Motion of the Clock, by the Tranſits of the fixed Stars, as often as the Weather permitted, making uſe of a Teleſcope which moved in the Plane of the Meridian; with this Inſtrument I could be ſure of not erring above two Seconds in Time. The Clock was kept conſtantly going, without having either the Hands or Pendulum alter'd, from the 9th of *June*, 1722. to the 14th of *October*, 1725. being three Years and four Months.

For the firſt Year, I wrote down every Day, the Difference between the two Clocks, with the Heighth of the Thermometer, not omitting the Tranſits of the Stars, as often as it was clear. The Reſult of all the Obſervations was this, That the Irregularity of the Clock, with the Quickſilver Pendulum, compared with the Tranſits of the Stars, exceeded not, when greateſt, a ſixth Part of that of the other Clock with the common Pendulum; but for the greateſt Part of the Year, not above an eighth or ninth Part; and even this Quantity would have been leſſened, had the Pillar of

Mercury been a little ſhorter; for it differed a little the contrary Way from the other Clock, going faſter with Heat, and ſlower with Cold; but I made no Alteration in the Length, to avoid an Interruption of the Obſervations. To confirm this Experiment the more, about the Beginning of *July*, 1723, I took off the heavy Pendulum from the other Clock, and made another with Quickſilver, but with this Difference, that inſtead of a Glaſs Tube, I made uſe of Braſs, and varniſhed the inſide, to ſecure it from being injured by the Mercury. This Pendulum I have made uſe of ever ſince, and find it about the ſame Degree of Exactneſs as the other. The Reaſon, why this kind of Pendulum is more exact than the common Sort, will be evident to any one, who conſiders, that as Heat lengthens the Rod of the Pendulum, at the ſame Time it increaſes the Length of the Pillar of Quickſilver, and its Center of Gravity is moved upwards: And when by Cold, the Rod of the Pendulum is ſhortened, the Pillar of Quickſilver is likewiſe ſhortened, and its Center of Gravity carried downwards; by this Means, if the Column of Quickſilver be of a proper Length, the Diſtance, between the Point of Suſpenſion and the Center of Oſcillation of the Pendulum, will be always nearly the ſame upon which the exact Motion of a Clock principally depends. Were the Pendulum of a Clock to remain invariably of the ſame Length, yet ſome little Inequalities would appear in its Motion, from the Difference of Friction ariſing from the Imperfections of the Materials, as well as different Degrees of Foulneſs; upon which Account, the Force communicated to the Pendulum, would not be conſtantly equal, which would cauſe ſome ſmall Alteration. But when the Pendulum is very heavy, and vibrates in a ſmall Arch, and the Workmanſhip of all the Parts is well per-

formed, there will be very little Inequality in the Motion, beſides what proceeds from Heat and Cold.

In making uſe of Quickſilver for a Pendulum, by varying the Diameter of the Veſſel that contains it, or the Thickneſs of the Rod of the Pendulum, whether it be of Braſs or Steel, they may be reduced nearly to an Equality as to the receiving, or retaining the Impreſſions of Heat or Cold, upon which the greater Regularity of the Motion depends; and particular Care ought to be uſed to free the Mercury from all Blebs of Air, otherwiſe their great and ſudden Expanſion, or Contraction, may cauſe a conſiderable Diſorder; but the Air may as eaſily be excluded in this Way, as in a Barometer, and the great ſpecifick Gravity of Quickſilver, renders it a proper Material for the Weight of a Pendulum.

F I N I S.

LONDON, Printed for W. and J. INNYS, Printers to the *Royal Society*, at the Weſt End of *St. Paul's Church-Yard*. 1726.